EME

ELECTROMAGNETIC ENERGY

Evaluation and Management for Antenna Sites

10/9/97 Revised 12/27/2001

The purpose of this document is to provide information to assist the reader in understanding the concepts required to comply with FCC guidelines for human exposure to Electromagnetic Energy at antenna sites. This information is not intended to replace a structured training program, but only as a first step in structuring an Electromagnetic Energy compliance program. The procedures presented in this document represent one approach for meeting FCC requirement; other procedures may also meet the FCC guideline and the procedures presented here may be revised from time to time to reflect engineering advances and technology changes.

Any reproduction of this report should be done in color to properly communicate information relative to recommended RF safety signage.

MOTOROLA

Bryan Corley
Senior Staff Engineer

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1. INTRODUCTION

In August 1996 the Federal Communication Commission (FCC) adopted new guidelines for evaluating the environmental effects of radiofrequency (RF) energy from transmitters on wireless communication sites. While there is no scientific evidence that RF emissions from these sites operating within established safety guidelines pose a health risk, fields close to antennas on transmitter sites must be understood and care must be taken to assure safe operation during maintenance. The guidelines adopted by the FCC provide considerable margins of protection from any known health risk.

The purpose of this paper is to discuss some of the issues involved in analyzing and understanding the **ElectroMagnetic Energy (EME)** environment that may exist on a complex communications site. A complex site is not only a site with hundreds of transmitters, antennas, and some broadcast, but any site with more than one RF transmitter. Considerable investigation has been done to understand the levels of exposure associated with such facilities, but little has been written on the implementation of procedures to insure operating conditions in compliance with the FCC guidelines.

The world is requiring more and more wireless communication. These include: cellular, PCS, ESMR, paging, basic two-way radio, broadcast, etc. Each of these services require transmitters and, in the past, each service would typically develop its own sites and exist alone. With the dramatic growth of these services, however, has come a growing incentive and need for collocation.

Collocation is the collection, or grouping, of transmitters for different communications services at a single site. Pressure for collocation comes from the need for more sites to satisfy public demand for more communications services, as well as public reaction to the proliferation and location of those sites. This will create communications sites more dense than has ever been dealt with before. Even today it is not uncommon to find successful communications sites full and bursting at the seams. In order to accommodate this natural growth in antenna density more locations to consolidate communication transmitters are needed.

While collocation is a logical response to the marketplace factors outlined above, it presents challenges to the companies providing these services. As more transmitters are added to a site, the density of RF generators and EME increases. This is not unlike the situation found on popular mountaintops surrounding large metropolitan cities. The best mountaintops have a high density of broadcast and communications sites. Because these are usually located on a common ridge or peak, the RF density may at times approach recognized exposure limits.

In this paper, we will discuss some of the issues that must be considered in the management of a complex communications site. These considerations are important in order to ensure the operation of sites within recognized exposure limits. The RF density increases with the increase in the number of transmitters. However, operating conditions in compliance with the FCC guidelines can be assured by the use of basic principles.

📖 Indicates summary information or examples.

☞ Indicates important information that should be carefully studied.

2. ENVIRONMENTAL EVALUATION

The possible health effects associated with exposure to **ElectroMagnetic Energy (EME)** have been studied for more than half a century. Scientists first identified the exposure threshold above which RF energy may cause adverse biological effects. The only established adverse effect of RF energy relates to the heating of tissue. Standard-setting bodies then set recommended exposure limits that are substantially below this threshold by at least a factor of 10 or more. With this substantial built-in margin of protection, these standards constitute reliable science-based guidelines for safe human exposure. Internationally, EME exposure standards exist in many countries. In the United States, one accepted standard comes from the American National Standards Institute C95 committee formed in the late 1950's. This committee has undergone many changes and implemented several standards. In 1988 **the Institute of Electrical and Electronics Engineers (IEEE)** became the sole sponsor of the C95 Committee, and the committee became the IEEE **Standards Coordinating Committee (SCC)**, SCC28. In 1991 IEEE adopted their current standards as IEEE C95-1991. These standards were subsequently recognized by ANSI (American National Standards Institute) in 1992 as the ANSI/IEEE C95-1992 standard for safety levels of radio frequency exposure. The exposure limits in the ANSI standard are similar in many respects to those set by the National Council on Radiation Protection and Measurements (NCRP), an independent organization chartered by the U.S. Congress.

The Federal Communication Commission recently adopted guidelines which generally followed the recommendations of expert health and safety agencies such as the EPA, FDA, OSHA, NIOSH, and others, to adopt field and power density limits as recommended by the NCRP Report No. 86 and the SAR limits from the ANSI/IEEE C95.1-1992. The FCC has stated that its latest exposure guidelines present the best scientific thought and are sufficient to protect the public.

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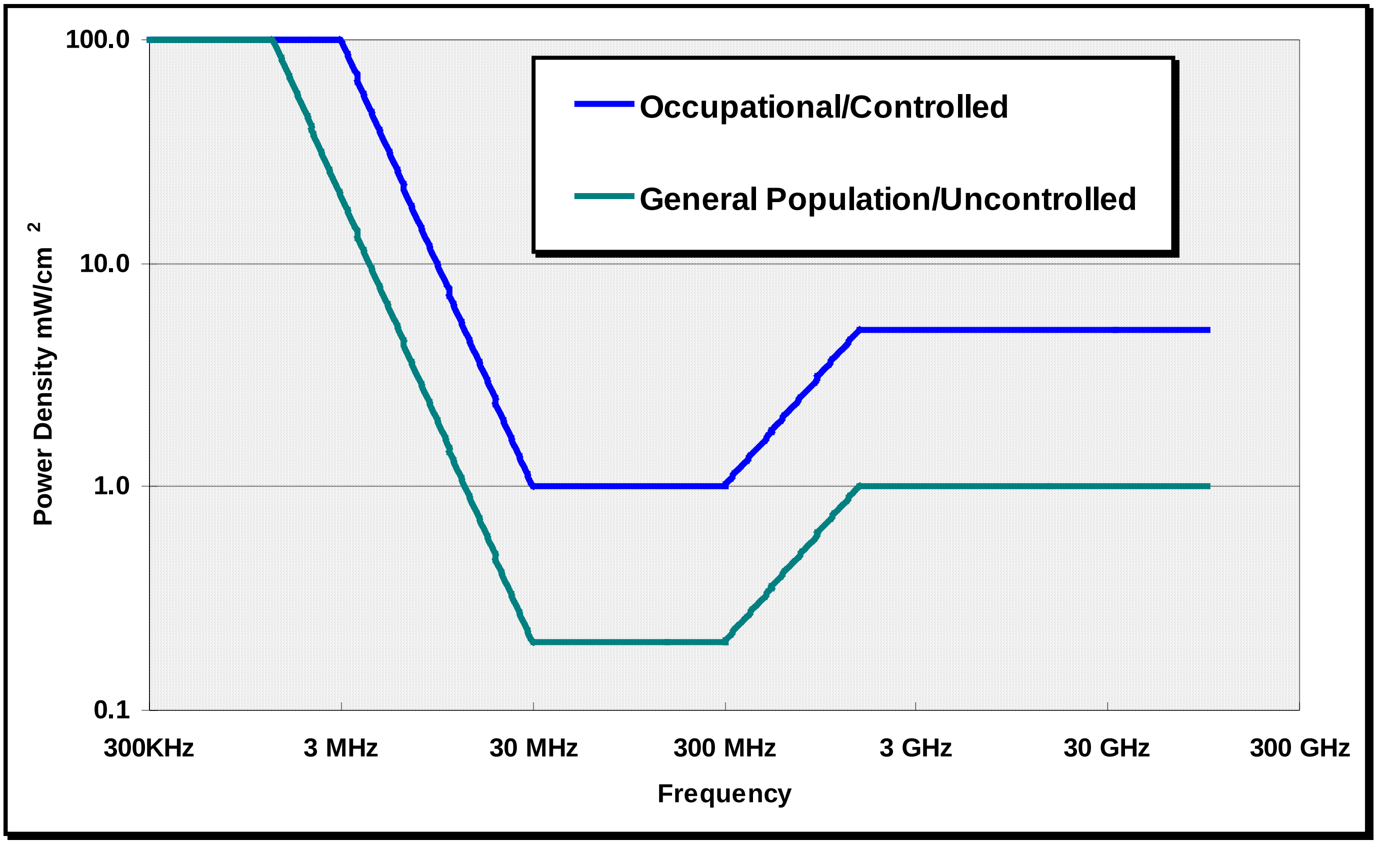
2.1 Exposure Standards and Limits

With the publication of the SCC28 standard as ANSI/IEEE C95.1-1992, a number of new elements were added to prior ANSI standards. These changes included modification of the exposure limits and the classification of exposure environments as Occupational/Controlled and General Population/Uncontrolled. Exposure limits in the new guidelines adopted by the FCC are specified in terms of **Maximum Permissible Exposure** (MPE) as a function of frequency; MPE's are given in units of electric and magnetic field strength and power densities. For exposure to multiple frequencies, the fraction (or percentage) of the MPE produced by each frequency is determined and these fractions (or percentages) must not exceed unity (or 100 percent).

If the RF fields at a specific location are composed of four frequencies and their fields represent the percentages of the applicable MPE for Occupational/Controlled environments as identified by the FCC are shown below, the resulting exposure can be expressed as 85% of the allowable Occupational/Controlled MPE and continuous exposure would be in compliance with the FCC limits.

Frequency (MHz)	Measured Power Density	MPE (Occupational/Controlled)
155.025	.25 mW/cm^2	25%
465.0125	.54 mW/cm^2	35%
955.0125	.48 mW/cm^2	15%
851.0125	.28 mW/cm^2	10%
Total Exposure		**85%**

Different limits apply to different circumstances ***(see Chart 1)***, based on whether a person at or near a specific site knows or is informed and has control of potential RF exposure. **Occupational/Controlled Environment** limits apply to individuals who should know that there is a potential for exposure as a requirement of employment, or as the incidental result of transient passage through areas that may exceed exposure levels beyond the General Population/Uncontrolled environment MPE's. For example, a maintenance technician who performs work on transmitters should be aware -- due to training and the nature of his work -- that transmitters produce RF energy. Because of the knowledge and understanding that exposure is possible, this individual would be evaluated against the Occupational/Controlled environment limits. **General Population/Uncontrolled Environment** limits apply to individuals assumed to have no knowledge of or control over their possible exposure to RF energy. If the technician in the example above brought his family to the same area, the situation would change. Since the family members would not be assumed to have knowledge or understanding of the RF environment, their exposures would be judged against the limits for General Population/Uncontrolled environments. The technician, however, would be evaluated against the Occupational/Controlled environment limits. Simple understanding or precautions can assure that RF levels at or near an antenna site do not exceed maximum permitted exposure levels. The MPE exposure levels for General Population/Uncontrolled environments are five times lower than the MPE exposure levels for Occupational/Controlled environments. The technician, in the above example, could be exposed to a power density of 3mW/cm^2 from a 900 MHz transmitter while the family members could only be exposed to 600uW/cm^2.



FCC Adopted Maximum Permissible Exposure Limits
Chart 1

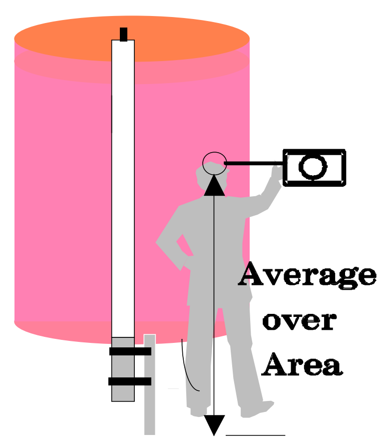
2.2 Compliance Analysis

2.2.1 Spatial-peak

The maximum RF energy across the area of the human body (about six (6) ft high) that an individual can be exposed to, is considered the **Whole Body Peak (WBP)**. This level should be considered as the highest level that is found in the area of interest. If during the evaluation of an area for exposure there are no WBP exposures above the MPE being considered, the area is considered below the limits and requires no additional evaluation.

2.2.2 Spatial-averaging

If, during the evaluation of an area for potential exposure, it is determined that there are areas where peak levels (WBP) will exceed the MPE, then spatial-averaging is required. Spatial-averaging considers the whole area of the human body in the evaluation of exposure. If there is an area that has RF fields above the applicable MPE, additional vertical measurements should be taken to understand the levels between ground level and two (2) meters (about six (6) ft high.[1]) The average of these vertical measurements is the Spatial-averaged exposure, which is used to evaluate compliance with the MPE.



[1]The ANSI/IEEE C95.1 - 1992 standard uses a height of 2.0 meters.

2.2.3 Time-averaging

MPE's in the guidelines are in terms of a time-averaged exposure, typically either 6-minute for Occupational/Controlled MPE or 30-minutes for General Population/Uncontrolled MPE. The averaging times are used to regulate the energy absorption rate in an individual exposed to RF fields so that the total energy delivered over the averaging time does not exceed FCC guidelines. This permits short duration exposure to much higher level fields as long as the average value over the prescribed time remains within the MPE.

> 🕮 The FCC Maximum Permissible Exposure (MPE) is time and spatially averaged. It is therefore permissible to exceed the numeric values of the MPE for brief periods of time and in some locations of space as long as the average exposure does not exceed the limits over the time and space indicated.

☞ While time averaging is considered an acceptable mechanism for managing high exposure levels, it requires considerable attention and consideration. There is potential for error and thus, the use of time averaging alone generally should be avoided. If situations are encountered where levels exceed the exposure permitted with spatial-averaging, then other means should be utilized to reduce exposure. There are situations however, where time averaging may prove to be an acceptable method available to control exposure. One of these situations is tower climbing. While on a tower, a climber may move through fields that are in excess of the limits for continuous exposure. If a steady rate of ascent is maintained the time-weighted averaged exposure can be maintained below the limit allowed in the guidelines.

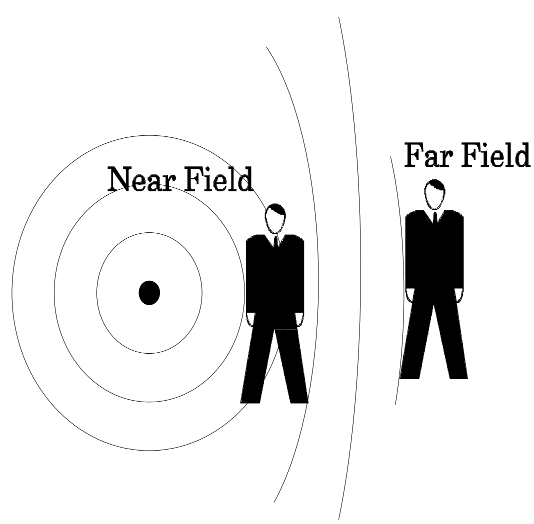
2.3 Exposure Evaluation

Evaluating possible RF exposure levels can be done using both theoretical models and physical testing. Modeling a site allows the tester to be aware of situations and anticipate locations where close physical examination is required.

> 🕮 The maximum exposure allowed by the FCC limits is 100% of the MPE, averaged over both time and body height. To provide a margin of tolerance to ensure compliance, in many cases an additional factor of 3 dB or 50% should be adopted as an action threshold. Any levels above 50% of the applicable MPE should have action procedures to maintain compliance.

2.3.1 RF Modeling

Modeling is the theoretical calculation of RF fields based on the situation. With a minimum amount of data, the field strength can be estimated before actual testing begins. To fully apply modeling one must first understand the characteristics of the antenna radiating in free space. The field radiates from an antenna like a ripple in the water after a pebble is thrown. The closer to the source, the more curved the wave front will be. As you get further from the source the circle becomes very large and the wave front has less curvature. Far from the source, the field appears planar. The field will still be curved but within the limits of observation it appears to occupy a flat plane in space, e.g., plane-wave radiation.

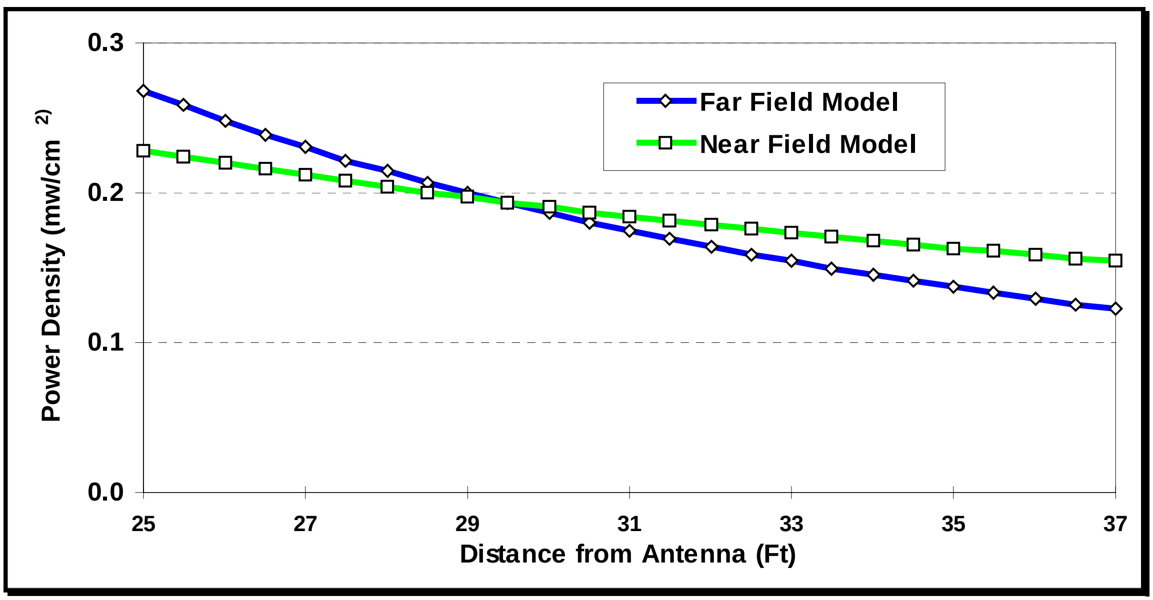


Close to the antenna is a region referred to as the near field. Within this region the spatial characteristics of the RF fields are very complex. The average power density within the near field varies inversely with the distance from the antenna. In other words, as you increase the distance from the antenna, the power density is reduced inversely with distance, D. This is the so-called $\frac{1}{D}$ region.

Further from the antenna we reach the far field. In the far field, the beam has developed and propagates in a behaved manner. In the far field, as you increase the distance from the antenna the power density decreases inversely with the square of distance. This is the so-called $\frac{1}{D^2}$ region. This signal intensity characteristic is commonly used to predict coverage. Far field calculation of signal strength is the normal approach for estimating signal strength a mobile receiver will receive.

From the standpoint of anticipating the power density a person will be exposed to from an antenna, both the near and far fields must be understood. If you predict the RF levels very near an antenna based on the square of the distance, as is indicated in the far field formula, the calculated levels increase faster than really occurs close to the antenna. There is a point called the crossover point where the two fields meet. Before this point the power density drops off linearly and after this point the signal reduces as an inverse square relationship. If both formulas are considered there is a point of intersection. This crossover point we define as the boundary of the near field and far field.

The power density decreases much faster in the far field than the near field. There is a distance from the antenna were the field strength of near field and far field are equal or intersect. The point of intersection (Crossover point) is the boundary for the two zones.

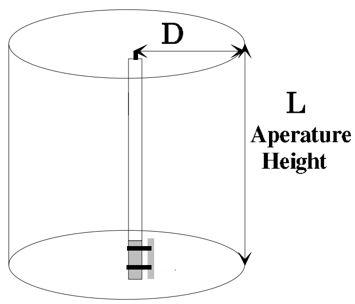


Example of Near Field/ Far Field Cross over
Chart 2

The data in ***Chart 2*** represent the crossover for a 6 dBd gain omni antenna that is 9 ft in length. As the aperture length and gain change, the crossover point will also change greatly. For the example above, the crossover point is approximately thirty feet. For an antenna with 10 dBd of gain and an aperture length of 13 ft, the crossover point will be over one hundred feet. A 3 dBd gain antenna with an aperture length of 1.5 ft will have a crossover point of only 3 ft.

2.3.1.1 *Cylindrical Model*

For vertical antennas, with omnidirectional horizontal patterns, the power density in the near field can be estimated using the circular radiation pattern and the height of the antenna. The area of a cylinder placed over this antenna is assumed to be uniformly exposed to the power radiated by the antenna; no RF is emanated from the top or bottom. This power density is approximately the same as the average power density an individual of a specific height would be exposed to when standing next to the antenna. This formula is referred to as the Cylindrical Model since it utilizes a cylinder for the modeling.



$$S = \frac{P}{2\pi DL}$$

S = Power Density (mW/cm^2)
P = Total Power into Antenna (mW)
D = Distance from Antenna (cm)
L = Length of Antenna Aperture (cm)

> Shorter antennas result in higher fields and exposure for a constant power. The greater the power, the higher the EME field. The shorter the aperture, the higher the EME field. The closer to the antenna, the higher the EME field.

2.3.1.2 *Spherical Model*

In the far field, the radiation pattern becomes developed and does not change with distance from the antenna. The maximum radiating power density becomes related to the gain of the antenna. In the far field the power density decreases as the square of the distance. With an isotropic point source (omnidirectional in all directions) the power density can be envisioned as the source power distributed over a sphere having a radius equal to the distance from the antenna. When the antenna has gain, the maximum power density in the far field can be calculated using the formula below:

$$S = \frac{PG}{4\pi D^2}$$

S = Power Density (mW/cm^2)
P = Total Power into Antenna (mW)
G = Gain Ratio of Antenna based on an Isotropic radiator
D = Distance from Antenna (cm)

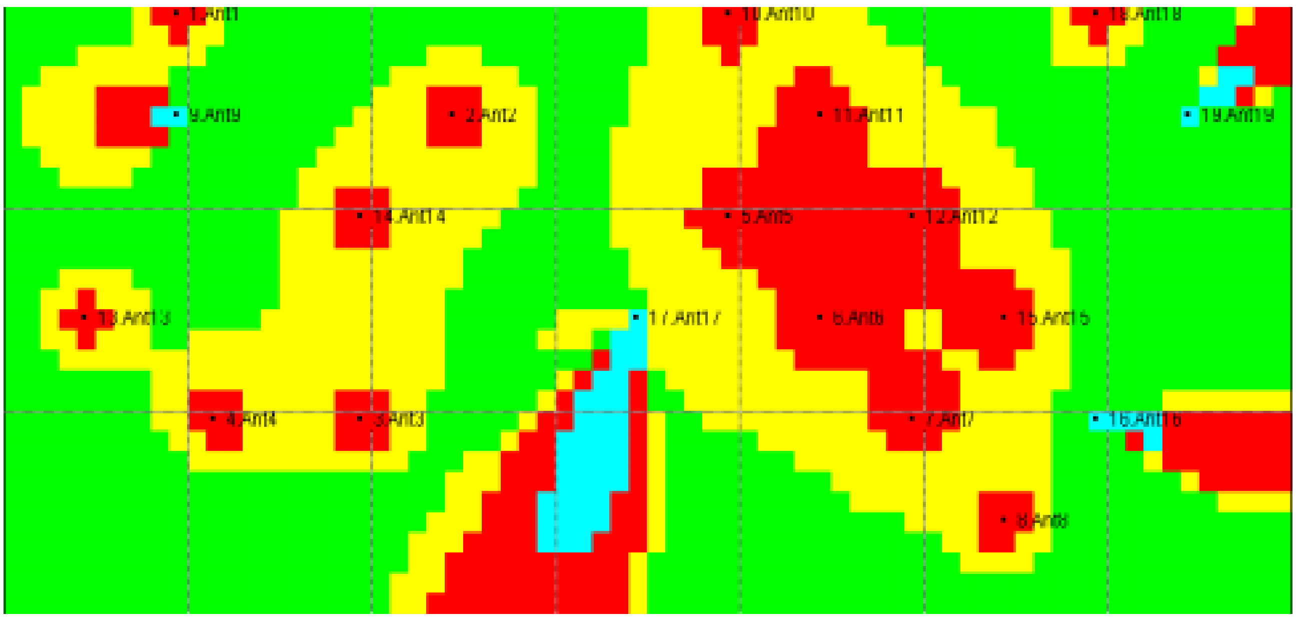
2.3.2 RoofView™ EME modeling software

[2]RoofView™ is a modeling software package that allows a theoretical study of site situations. The software creates a mosaic map of the area showing the EME levels **(see *Figure 1*).** The calculations can use different methods, different standards, antenna heights, and uptime for evaluation. There are two versions:

- RoofView™ is the building version showing EME situations on a single plane.
- TowerCalc™ is used to model towers. This will allow the EME situation on any level of the tower to be understood.

The software runs on Excel 5.0 for Windows 3.1 and NT and Excel 7 for Windows 95. The information needed to create a model and generate a zoning map is:

- Transmitter Power into Antenna
- Frequency
- Antenna mount designation
- Antenna location on roof
- Antenna Characteristics
  - * Gain
  - * Aperture Length
  - * Mounting Height



EME Zone map of a complex rooftop antenna site
Figure 1

RoofView™ calculates and plots a pictorial representation of EME levels. Antenna fields can be expressed directly as a percentage of user selectable MPEs. This is analogous to running a range prediction coverage map. During RF system design an understanding of coverage is important. During site design EME evaluation is important.

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[2] Trademark RoofView™ and TowerCalc™ are licensed to Richard Tell Associates, Inc., Las Vegas NV. Additional information can be found on Website: www.**radhaz.com**

2.4 EME Zoning

After the exposure levels are determined an evaluation and classification should be performed. The classifying of the exposure allows site managers to understand the complete situation and develop procedures to ensure exposure to employees and contractors is maintained below the acceptable limits.

Classifying exposure focuses on comparing the levels found against the Occupational/Controlled MPE. As the term indicates, MPE is the maximum permissible exposure an individual should encounter. To further classify areas, a standard color coding can be adopted to clearly show the EME levels.

On a site where RF transmitters and their associated antennas are located, usually, it is necessary to restrict the access of the general population. This area frequently is bounded by walls, fences, and other natural or man made structures. Within this area three zones (Green, Yellow, and Red) will be used to determine the requirements for compliance to the FCC guidelines

2.4.1 Green Zone

The green zone is any area where the time (as appropriate) and spatial-average is below 20% of the Occupational/Controlled MPE. The areas so classified afford the highest level of protection for individuals working in RF fields. There is no time limit and no special EME safety practices are required for these areas. Individuals working in this zone may need only basic EME awareness. This can be conveyed with signs, plaques, or awareness videos to provide the information necessary to create an awareness and understanding of the environment.

> Green Zones denote the lowest EME levels at the site. This area is usually associated with equipment rooms, ground areas around towers, and other areas significantly removed from transmitting antennas. The green zone is unique because the exposure levels are below the General Population/Uncontrolled environment MPE's. Care and proper consideration in site design should be done to ensure these levels are maintained. On high-density sites annual (or more frequently if required) evaluations should be done to ensure compliance.

Equipment rooms and areas around the base of towers should always be required to have fields low enough to allow a green classification. The verification and certification of this low level may be required on some sites. If locations are discovered in excess of these levels, changes and modifications must be incorporated to maintain green zone status. Some methods to maintain green zone levels are:

- Proper maintenance of RF transmitters. This includes ensuring all shields are maintained properly and installed correctly.
- Not allowing transmit antennas inside equipment rooms or near the ground level of sites.
- Ensuring all microwave dishes are directed away from facilities.
- Proper use and installation of transmission lines and connectors. When waveguide carrying high power is used, verification of fitting integrity must be performed to ensure there is no RF leakage.

2.4.2 Yellow Zone

The yellow zone is any area where the spatial-average is between 20% - 100% Occupational/Controlled MPE. While the fields in this area are within acceptable limits, caution must be exercised because nearby locations may exceed the limits. Therefore, individuals in these areas should have heightened awareness and understanding of their potential for exposure. Normally, there will never be a yellow zone without another zone of higher level in the vicinity. Personnel without EME awareness training should not frequent this area regularly. Only personnel with the proper knowledge and understanding of EME compliance procedures should be allowed to work in areas designated as yellow zones. Caution signs should be posted to inform personnel of the EME situation.

Yellow zones should be posted to insure all personnel entering understand the area is controlled. The EME levels in a yellow zone are below the MPE for Occupational/Controlled environments, but not for General Population/Uncontrolled environments. Only individuals who have the knowledge and requirement should be given access.

2.4.3 Red Zone

The red zone is any area where the spatial-averaged levels fall above 100% of Occupational/Controlled MPE. When locations are found to require red zoning, special procedures, engineering, or restricted access must be implemented to ensure compliance. Some procedures that can be implemented are:

- Restrict Access
- Lock-out/Tag-out of transmitters during maintenance of antenna system
- Control of antenna types used for site design
- Re-engineer site to reduce EME fields
- Measure and consider uptime

2.5 CHARACTERIZATION ZONING

The level of RF energy to which one is exposed is called Exposure. The quantity of exposure depends on the duration and strength of the field. In most cases the characteristics of a site will determine the EME exposure potential. **Understanding** these characteristics will aid in predicting and preventing levels that exceed the FCC Guidelines and allow the site manager to establish the proper procedures for workers who frequent these areas.

2.5.1 Buildings

Building sites are normally in dense, metropolitan cities. The buildings used are normally the highest structures in the city and offer the unique opportunity of height without the need for a long feedline. The facility which houses the radio transmitters is normally close to the antennas which reduces the loss between the antenna and transmitter, allowing maximum power to the antenna. While this maximum power provides extended range it increases the EME levels around the antennas. The main determinants of EME are frequency, power into the antenna, and aperture height. The greater the power, the higher the EME field. The shorter the aperture, the higher the EME field for a given power.

On buildings, the antennas are generally mounted on the roof. This mounting arrangement is normally laid out on a single plane and distributed in a grid arrangement, within the confines of the roof. The mounting is normally on a pipe structure and the separation can be as close as three (3) feet in some cases. This arrangement provides for maximum mounting density, but it may leave little space for the workers performing maintenance. Any worker attempting to change an antenna, repair a cable, or perform general maintenance may be exposed to high levels of RF energy from other antennas surrounding the work area.

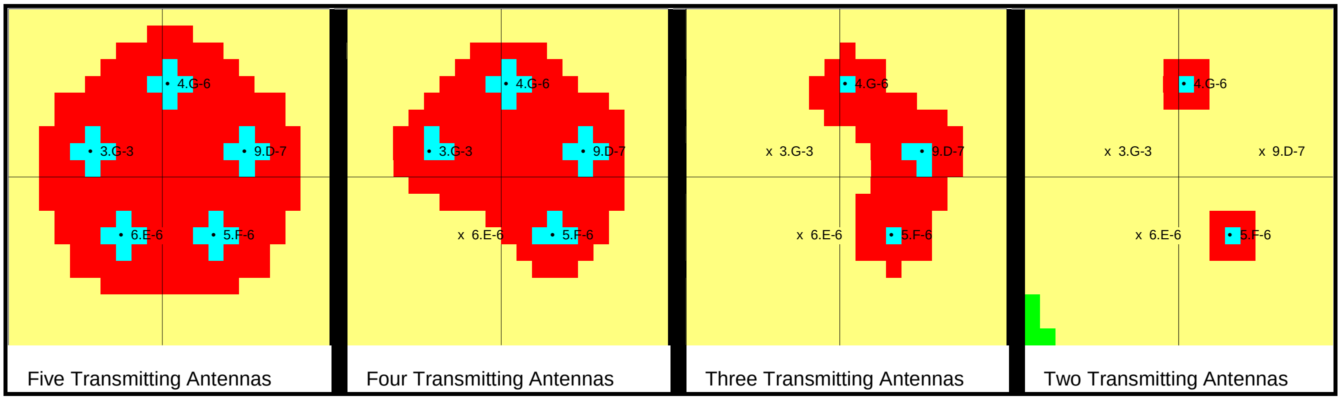
Proper engineering design should be used to prevent this situation. By reducing all the fields on a building the potential for high exposure is eliminated and provides the best compliance resolution.

2.5.2 Towers

Towers are antenna supporting structures that can be found in various locations ranging from central metropolitan, to isolated rural locations. Normally, the towers are designed to elevate the antennas in accordance with the intended coverage area. This can vary from a hundred feet for cellular to two thousand feet for two-way communications. Regardless of the height of the supporting structure, the characteristics are the same. The application of the antennas that are being supported determine these characteristics. Cellular towers usually have directional antennas mounted on a single face to define a sector. There may be several faces and several directional antennas per face. A two-way tower can have several antennas mounted in a star configuration to maximize the density of antennas at a position on the tower. Additionally there can be several star mounts on a single tower.

With respect to EME, the cellular configuration presents less exposure to people working on the tower than the two-way tower configuration because the RF radiation of the directional antenna is aimed away from the tower. There is a significant power difference between the front and the back side of the antenna. This difference is called front-to-back ratio. While the front-to-back ratio can be as great as 25 dB in the far field it is less well developed in the near field. There is still reduction of the exposure of the worker in the near field behind, as compared to the front of the antenna, but the amount may be considerably less than the advertised far field front-to-back ratio.

The situation on two-way towers is significantly different. As workers climb up the tower they may encounter several antenna mounts at various locations on the tower. These mounting areas can contain various types of transmitters ranging from paging transmitters with hundreds of watts of power to large antennas for transmitters in the 35 MHz frequency range. While the antennas and the resulting mounting arrangement can be considerably different, in some conditions the EME levels may approach or exceed the FCC guidelines. In the case of the paging transmitter, the antenna will normally be an omni configuration with an aperture length of four (4) to fifteen (15) feet. The antenna will be mounted from four (4) to six (6) feet from the tower. Fields directly adjacent to the aperture will present the highest levels. Because of this, workers should use caution while working or stopping directly in front of these antennas unless the transmitters are deactivated. If the antenna is grouped with other antennas at the same level more than one transmitter may need to be deactivated. Another important characteristic of paging is the duty cycle of the transmitter. The importance of duty cycle will be discussed in detail later.



EME Zone map of a tower mounted star cluster mount or candelabra (Resolution 1 sq. ft)
Figure 2

Star cluster mounts **(see Figure 2)** or candelabras present a significant issue in the management of EME on towers. If there are five (5) to eight (8) antennas mounted in a circle and these antennas are located five (5) feet from the tower there is the potential for an EME level in the center that exceeds the limits. Because the center is the tower, workers must ensure they understand the fields while entering this area. Figure 2 shows the computed effects of several transmitters using the EME modeling program described above. Each square pixel represents one (1) square foot of resolution. This simulates the effects of five PD-10017 antennas with 100 W into the antenna at 900 MHz. A worker entering this area may be exposed to EME levels above the applicable MPE and should take appropriate steps, such as moving quickly through the area, to assure compliance with recognized exposure guidelines. What makes this situation difficult to manage is the fact that the field and the resultant high EME levels from all the antenna fields overlap and add. While this situation can exist, the fields are reduced by the cable loss associated with the height of the candelabra, and are therefore more manageable. Most candelabras are mounted on top of a tower.

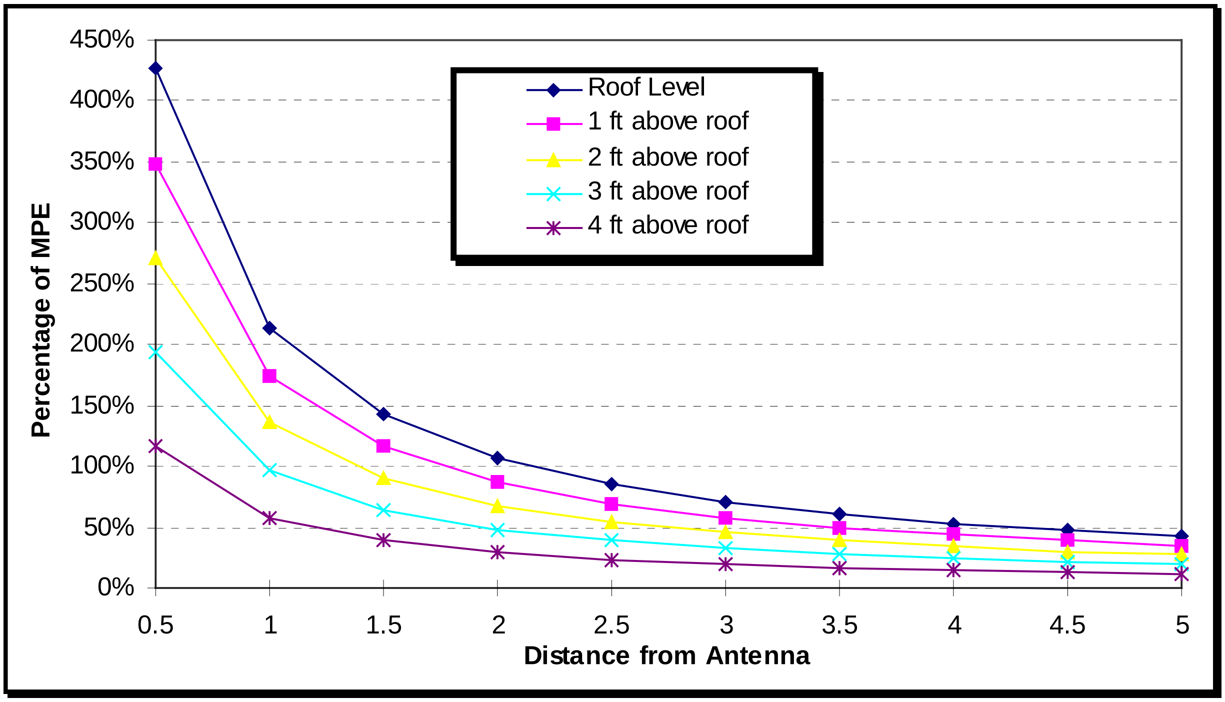
Because of the cable loss associated with towers, the power into the antenna is significantly lower than buildings and mountain-top sites. This loss between the transmitter and antenna reduces the power and ultimately the fields produced. Higher frequencies have higher line loss, which significantly reduces the power at the antenna. This fact is very important and proves to significantly reduce the fields produced on tall towers.

> 📖 Candelabra and star mounts present unique compliance and maintenance situations due to the additive nature of EME exposure at these locations. Insertion losses of transmission lines reduce the power into the antennas and reduce the likelihood of strong fields on clusters located at high levels on tall towers. For equal transmitter power, the higher the frequency, the higher the insertion loss; thus EME levels are lower on tall towers.

3. ENGINEERING CONSIDERATIONS

3.1 Antenna elevation

One common technique for reducing the RF levels expected on large roof tops is to elevate the antennas above the roof. Elevating the antennas raises the EME fields above the roof and reduces the power density to which an individual at roof level will be exposed. The results of elevating antennas are illustrated in ***Chart 3.*** These data are based on the EME fields produced by an 850 MHz SMR antenna. Ten 150 watt transmitters through a combiner drive the antenna. The resultant 550 watts of power is fed into a 13 foot omni antenna. This type of antenna configuration is not unusual on rooftops.



Exposure Vs Antenna Height Above Roof
Chart 3

The resultant exposure possible can be above the MPE when the antenna is mounted at the roof level. From the chart, fields in excess of 200% of the Occupational/Controlled MPE are encountered within one (1) ft of the antenna. While this seems extremely close, a technician walking down the center of an antenna grid with four (4) foot centers will be two feet from any antenna at any time. Two feet from this antenna mounted at roof level it is possible for the exposure to be over 100% of the same MPE. If this situation is compounded with several antennas having the same power density, the levels in this walking area could be above the MPE. For this reason every effort should be given to reducing the fields at the roof level. The most effective technique for reducing the fields on a building, while maintaining constant radiated power, is raising the antenna. Raising the antenna four (4) feet above the roof reduces the EME field strength at the roof level to about 50% of the MPE at one (1) foot from where the antenna was. If the antenna is raised six (6) feed above the roof the fields are reduced more than 90%.

The most effective technique for reducing EME levels is elevating antennas on buildings and extending antennas away from the tower.

3.2 Extend antennas away from towers

Tower contractors climbing the tower must pass through fields created by active antennas on the tower. Antennas mounted on short sidearms or mounted directly to the tower produce high levels of exposure to tower climbers. It is a good engineering practice to mount omnidirectional antennas a minimum of five feet from the tower.

3.3 Collocated broadcast transmitters

Areas with broadcast transmitters can have fields created by grating lobes from the antenna or fields developed directly by the main radiating beam. On broadcast-only sites these are the only field that must be considered in EME analysis. On collocated sites, the EME fields are a combination of the fields generated by two-way transmitters and broadcast stations. If the exposure from each contributor is considered independently and then added, the total MPE situation can be evaluated. The fields from the broadcast transmitter act like a blanket covering the area. If the fields from a preexisting broadcast station create a level of 15% Occupational/Controlled MPE there is only 85% of the MPE budget remaining. This requires the levels from the two-way transmitters to be lower than what otherwise would be required to maintain compliance. In some conditions extra cooperation between the broadcasters and two-way licensees may be necessary to ensure site compliance. In the areas that receive grating lobes from the broadcast transmitters, careful measurements must be done before compliance can be analyzed.

Consideration must be given to anyone working on antenna systems. If a person must climb into the fields of the broadcast antenna, coordination ahead of time must be done to reduce the transmitter power. Special consideration and care should be utilized when a person is required to climb through a field known to exceed 100% Occupational/Controlled MPE. On some sites the broadcast towers are mounted adjacent to the two-way tower. In this situation the fields from the broadcast transmitter will be very intense on the two-way tower. Maintenance activities must be coordinated when the broadcast station is collocated. The FCC requires broadcasters to cooperate during maintenance situations; however, they may elect special times to conduct maintenance.

3.4 Location of directional antennas

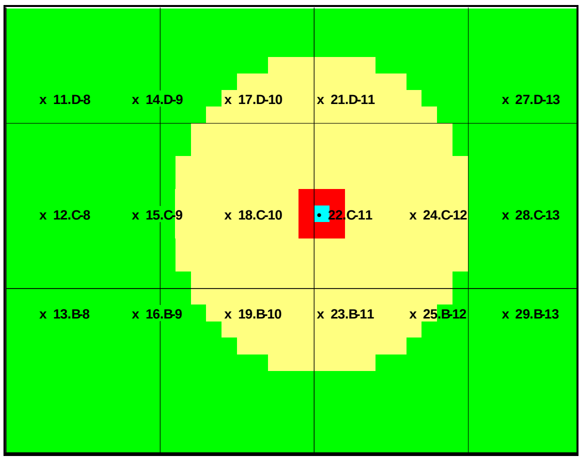
Directional antennas in the horizontal plane present a focused pattern for maximum coverage into a specific area. Even in the near field the levels in the beam of the antenna can be significantly higher than behind or on either side. Consideration must be given to the area and location the antenna is directed. Directional high-powered transmitting antennas should be located where the energy in excess of the Occupation/Control MPE is directed away from any area frequented by workers. Additionally directional antennas should not be installed where they can produce fields higher than the General Population/Uncontrolled MPE in uncontrolled areas.

3.5 Antenna Selection

Antenna selection is important because it is directly linked to EME levels. The requirement for more antennas within a given horizontal space has created new designs of antennas. Within one radome several antennas can now be stacked on top of each other. The standard configurations are double (two), triple (three) and Quad (four) co-linear arrays. Aperture length directly affects the power density created. In the near field, a fifteen foot antenna driven with 500 Watts will have one third the power density of an antenna five feet long. Remember that near the antenna, the power density is related to the surface area of a cylinder placed over the antenna. A cylinder having one-third the height will have one-third the surface area and, hence will result in three times the power density. This is complicated even more when the five foot antenna is placed with other antennas in a common radome. This allows the power density, created by each antenna, to combine and increase the potential exposure of an individual. The technique of using triple and quad antennas is becoming increasingly popular as the space on mountain tops and towers becomes scarcer. Paging transmitters, sectored antenna systems, and digital networks represent only a few of the services requiring individual antennas. There is a finite antenna density that can be accomplished within a given area. Creative methods of combining or increasing the antenna structures must be developed. Consideration should be given to connecting lower power transmitters to the bottom portion of triple and quad radome antennas.

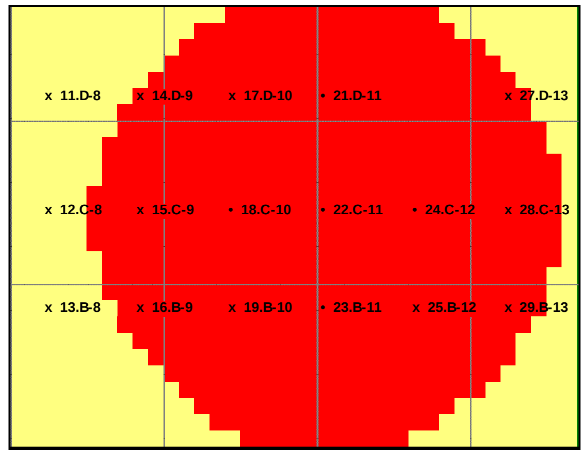
3.6 Mounting density of antennas

While the RF fields from one antenna may be below the MPE allowed, the combination of fields from several antennas can produce levels exceeding the Occupation/Control MPE. This can be easily seen in figure 4 and figure 5 which show the fields produced by one antenna and the fields produced by five antennas mounted at roof level with all transmitters keyed simultaneously.



Composite RF Fields with one antenna transmitting

Figure 4



Composite RF Fields with five antennas transmitting

Figure 5

The combined fields produce levels exceeding the MPE allowed in all areas surrounding the antennas. In these situations, some means of controlling exposure must be used. These techniques may include RF protective clothing, re-engineering the antenna system, or power shutdown or reduction when working in the area. While power shutdown or reduction may appear to be an effective technique, either may be impractical for wireless communications services. It is normally reserved for broadcast transmitters. One perfered method of addressing this is to elevate the antennas above the roof area.

3.7 Uptime

Complex antenna sites have a "personality" that makes them unique. The personality of the site is not only determined by the RF power, frequency, and manufacturer of the equipment, but by the operational characteristics. The RF level and frequency can be determined by understanding the equipment specifications, but operational characteristics can only be quantified by monitoring the usage. Because of the high number of pagers, paging transmitters will have a very high transmitter duty cycle. Trunking (SMR) transmitter activity will depend on customer loading density. This can range from transmitters rarely transmitting, to transmitters rarely not transmitting. Private customer equipment will have a very diverse usage characteristic that can not be predicted. The important point in understanding the characteristics of different services is that they can seldom be predicted.

Additionally, characteristics for transmitters will change due to cultural elements. Transmitters located in Las Vegas will have considerably different uptime characteristics than transmitters located in San Antonio, Texas or New York City. Tests have shown that a site will vary significantly from one time period to another. Sample measurements on a roof of a large building showed a variation in transmitter activity of over 30% between 11:00 a.m. and 2:00 p.m.

Uptime relates to all of the transmitter activity of a site. Uptime can seldom be predicted or characterized precisely, and thus usually must be measured. The amount of Uptime directly affects the EME exposure levels on a site.

In the consideration of site activity, there is an upper level of 100% uptime, or when all transmitters are keyed and actually energized. Actual usage would be the most accurate consideration, but least practical to implement. Actual usage varies greatly over time and antenna. Each antenna has an uptime characteristic based on density of combining, transmitter usage, and activity.

While the use of Uptime could provide a better approach to predicting the actual levels that could be encountered, it proves to be impractical. Determining the Uptime characteristics can be very complex and change with time. Only by constantly monitoring and adjusting the model can uptime be used. Uptime cannot be theoretically calculated, it must be measured. Measurement of uptime involves high speed scanning of frequencies over a long period of time. Only after thousands of activity observations taken over days of monitoring will the worst case, actual, and instantaneous uptime be understood. This complex procedure creates uncertainty. Practically the uptime that should be used in the analysis of complex sites usually is 100% or total uptime.

3.8 Antenna site documentation

Any evaluation is only as accurate as the data used to make the evaluation. Antenna site documentation is important and should be done in a standardized manner. For the analysis of EME fields there are two methods of documentation. One proves to be considerably more exact but both allow an engineer to understand the EME situation and apply the proper compliance procedures, if necessary.

3.8.1 Actual Documentation

Actual documentation provides an accurate picture of the site situation. Actual documentation can be used by engineers for purposes other than EME analysis. Proper documentation requires a detailed description of transmitters, cable, antennas, and location on the tower; that will require the following:

- Transmitter frequency by antenna mount
- Power out of transmitter
- Network loss between transmitter and antenna
- Antenna characteristics and specifications
- Antenna Location and standoff
- Uptime characteristics
- Areas frequented by personnel
- Layout of antenna field (roof or tower)

3.8.2 Categorization Documentation

Determining which transmitter is connected to which antenna on a site via which coaxial cable can be very expensive and in many cases is not necessary. Categorization documentation evolves determining the lowest loss coax and the highest-powered transmitter in any particular band. It is then assumed that all antennas for that band have this combination attached. By understanding the frequency, spacing, height and antenna characteristics of all antennas on the tower an approximation of the worst case EME situation can be determined. If this preliminary investigation proves to be compliant, then the actual situation will be compliant. Thus, this worst case scenario evaluation will assist in determining if a more detailed evaluation is required. This method of EME analysis requires a trained site auditor to only determine the components affecting EME compliance. This procedure will not provide the exact levels of the fields, but can be used to determine sites that require additional investigation using actual documentation.

Understanding your EME environment requires that an inventory of all generators of RF energy and the EME exposure potential be maintained for all facilities. This requires standardized documentation practices and regular updating.

4. Work Practices

The way an antenna site is managed, controlled, and operated directly relates to the quality of the site. All of the customers on a site not only have physical investments, but also rely on uninterrupted service. The requirements placed on all contractors, customers, and employees determine the quality of a site.

4.1 Training and qualification verification

A very specific part of worker contracting is verification of qualification and training. All contractors should have a basic understanding of EME awareness and show an understanding of site standards. All contractors are expected to be experts in their field and to be on top of changes in govermental regulations. Without regular training a contractor cannot expect to be on top of changing hardware, technology, and government regulations.

4.2 Physical access control

Antenna sites must have physical access control. The minimum requirement is locked gates to prevent vehicular access and locks on the facility. In most situations towers should have specific access control. Access to the site should not allow access to the tower. Tower climbing prevention should be accomplished with fencing around the tower, climb prevention on the tower, or locking barriers on the tower. Unauthorized climbing must be prevented to insure individuals climbing the towers understand the EME situation, are qualified, and possess the correct climbing equipment. The facility should be equipped with card access, where appropriate, to provide a direct history of traffic at the site. Card access will provide specific information on who comes and goes from the site.

4.3 Policing

Any policy controlling site administration must be enforced before compliance can be assured. Every effort should be given to ensuring all contractors understand, comply and support the policies of the site. Violation of policy should be grounds for disqualification of a contractor. It is a privilege to work on a site and the policies must be followed.

4.4 Chain of authority and reporting requirements

There should be site books or a site folder located at each facility. These documents will outline the policies and procedures for the site including a contact roster for emergencies and notifications. Additionally, any specific site situations or policies can also be contained in the site book.

4.5 Understand site responsibilities under shared conditions

There are situations where occupancy and management of a site involves other agencies or entities. This may be a situation where a site is located on a building, collocated with broadcast companies, shared mountain top, etc. In each of these situations, others can make decisions that can affect the safety and operation of the site. Every effort should be given to developing consolidated procedures that require the compliance of all parties. This protects their interests and safety as well as contractors and employees using the site. Control measures should be coordinated to allow safe tower maintenance. When other transmitters are involved, power reduction, lock-out/tag-out, or restricted time for maintenance may have to be used to assure RF exposure is controlled.

4.6 General Procedures

General procedures relate to normal practices that are common to all sites. These can be found posted at all sites on the “Guidelines for working in radiofrequency environments” placard, **(see example in section 5.1)**. These guidelines are:

4.6.1 *All personnel should have electromagnetic energy (EME) awareness training*

All workers entering a RF controlled area should understand their potential exposure and steps they can take to reduce their EME exposure. Awareness is a requirement of all workers. This includes not only field engineers, maintenance technicians and site designers, but also others such as site acquisition personnel, building management, and service oriented personnel. For example electrical, telephone, elevator and air conditioning mechanics as well as roof repair, painting and window washing crews. The FCC report and Order specifically indicates the requirement to make personnel at a transmitter site "fully aware" of their risk of exposure. Awareness training increases worker sensitivity to potential exposure, thereby assisting proper compliance within exposure limits. Awareness can be given in different formats, some may be video, formal classroom, and informal discussions.

4.6.2 ***All personnel entering this site must be authorized***

Only personnel who have been trained and understand the EME situation and other safety requirements associated with site work should be allowed access without escorts. When untrained individuals access the sites, trained escorts are required.

4.6.3 ***Obey all posted signs***

This guideline emphasizes the importance of observing and understanding the instructions on posted signs at the transmitter site. All safety signs play an important role in any safety program and just as any of these signs convey a specific message related directly to safe work in a particular environment, postings at transmitter sites are no different. For example, certain areas may be designated "NO ACCESS" unless certain antennas are shut down. It is important that these signs be understood and obeyed, to assure EME exposure below the FCC guidelines. The requirement for RF protective clothing for workers is another precaution that could be identified on signs designating areas of potential exposure in excess of FCC limits.

4.6.4 ***Assume all antennas are active***

Because most telecommunications transmissions are intermittent, the status of many transmitters that may be operating at a particular site will be unknown. It is important to assume that all antennas may be energized and to maintain a safe working distance from each of them. Only with special instruments to detect the presence of RF energy can it be determined a particular antenna is not energized at any given moment. While EME measurement surveys may have been performed on the site, these surveys do not assure that a specific antenna is not active at a given time.

4.6.5 ***Before working on antennas, notify owners and disable appropriate transmitters***

Before working on an antenna, workers must insure that all attached transmitters are deactivated. Most antennas at a transmitter site are being used for important communications. They may be used for emergency and safety purposes like fire protection, rescue dispatch and police communications. Although all attached transmitters must be turned off before touching and working on an antenna, in no instance should this be attempted before contacting the owners or operators. Coordinating with the individuals responsible for use of the transmitter will make sure that turning off the equipment will not cause a serious disruption of the service. Sometimes, this coordination may mean that the work will have to be performed at night or in the early hours of the morning. Lockout/Tagout tags should be used to make sure someone else does not inadvertently turn on the transmitter while work on the antenna is being performed.

4.6.6 ***Maintain minimum 3 feet clearance from all antennas***

Studies have shown that the EME fields close to two-way radio transmitting antennas can be strong enough to exceed the limits specified by the FCC guidelines. A three foot clearance is a practical approach to assure that exposure remains within FCC limits. This insures a distance is always maintained unless work is required on an antenna. Work on a specific antenna should only be accomplished after the attached transmitters have been turned off. A small increase in distance from an antenna can have a substantial effect on reducing the EME exposure. This is particularly important when working near other active antennas. This also applies when doing work on roof or tower mounted equipment like air conditioners, tower lights or window washing rigs.

4.6.7 *Do not stop in front of antennas*

When moving about at the transmitter site workers should avoid stopping near any antenna; they should continue on until they reach an area that is removed from their immediate vicinity. If they are going to take a break from work, or have lunch, they should select a place on the roof that will provide as much distance between them and the nearest antennas as practical. When climbing a tower, workers should select rest points away from antennas. Workers should always try to keep below or behind antennas to minimize their exposure to the main beam of the antenna. By continuing to move past high EME fields the average exposure will be minimized.

4.6.8 *Use personal RF monitors while working near antennas*

Special care must be exercised when working on or very near antennas. Although the EME fields cannot be sensed directly, transmitter activity can be detected close to an antenna with a personal RF monitor. Wearing such a monitor will allow workers to ensure that all connected transmitters have been turned off before they begin maintenance. As they approach an antenna, if the monitor alarms, they should get away from the antenna, determine which transmitters are still on and disable them.

4.6.9 *Never operate transmitters without shields during normal operation*

Some work at antenna sites involves trouble-shooting and repair of the radio transmitters. The shields within transmitter power amplifiers are there to prevent strong RF fields from radiating out of the transmitter cabinet. Operating the transmitter without shields could cause interference and exposure of the technician performing the service to EME levels in excess of the FCC guidelines. While shields must be removed for many maintenance tasks, they should always be properly reinstalled before returning the transmitter to normal operation.

4.6.10 *Do not operate base station antennas in equipment room*

Transmitting antennas should never be operated inside the equipment rooms, even for short term testing. This includes mobile magnet mount antennas attached to the top of transmitter cabinets as temporary installations. Using transmit antennas inside equipment rooms can increase the exposure to EME levels above FCC guidelines and create undesirable radiofrequency interference.

4.7 Site Specific Procedures

Site specific procedures that are unique to a particular site may need to be available to assure compliance to the FCC Guidelines. These can include:

- Special access
- Potential high EME exposure situations
- Special maintenance procedures for antenna repair
- Maintenance procedures unique to the site
- Special security procedures
- Special reporting procedures related to other tenants and owners

4.8 Operating Procedures

The conduct of contractors should be controlled and coordinated by the antenna site manager. All contractors, whether customer controlled or contracted directly with the management, must follow specific procedures. These procedures relate to safe operations that will be followed during installation and maintenance of antenna systems. Site procedures will prevail over contractor accepted practices and standards. Contractors must follow the guidelines for the site.

5. Signage

Various signs may be required on antenna sites. The minimum requirement is to post an EME caution and/or warning signs, as appropriate, wherever EME levels can exceed those associated with a green zone. This sign should be posted in a location that can be easily viewed by individuals that enter the areas of concern. Some areas that may be effected are building tops, towers, areas around broadcast, etc. This assures notice and understanding that the area has active RF transmitters. The sign should conform to the ANSI standards.

Posting of signs provides a convenient method to convey to individuals important information. While signs can be effective if used properly they can convey the wrong message and create undue alarm if used incorrectly. For this reason different signs are recommended for specific applications. These signs represent the best methodology available in conveying important information.

The standards used in creating these signs are:

Signal word- This word designates the degree of safety alerting, e.g. Warning, Caution, and Notice.

Symbol - The advisory symbol for identifying incident electromagnetic energy consists of black wavefronts radiating from a stylized point source. This symbol is defined in NEMA/ANSI Z535.3-1991.

Text Message - The text message should convey three things:

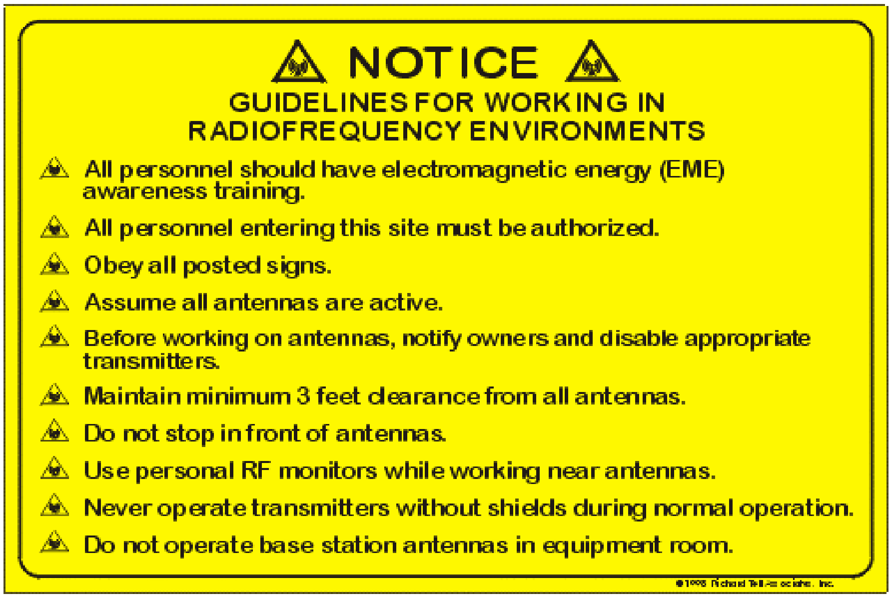
- What the safety issue is
- What action should be considered
- What authority the issue is based upon

These are used to designate the possible issues that can be encountered at an antenna site. These signs have specific implementation guidelines as outlined below. Improper implementation could result in inaccurate information being conveyed or unnecessary alarm being created.

Examples of signs that have been implemented in the United States are shown below.

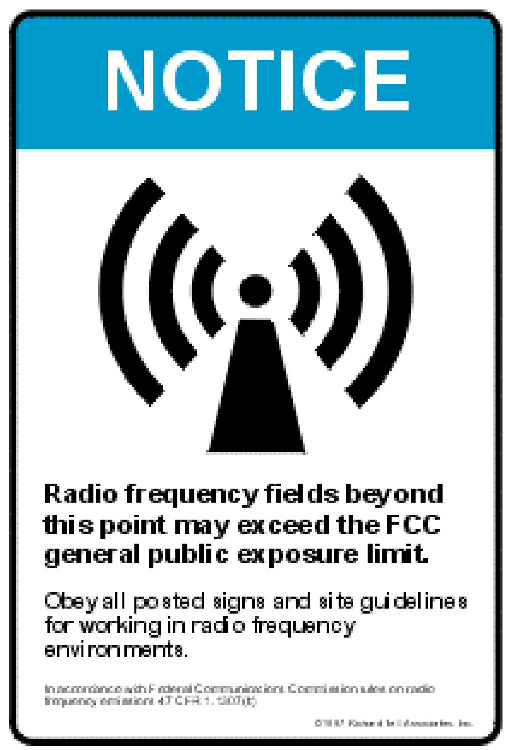
5.1 Site Guidelines

The site guidelines are posted inside the equipment room to make all workers aware of the normal requirements for site operation. The major intent is to insure that compliance is maintained at the site. Having the sign visually available informs and reminds all personnel and others who have proper access, of the rules for the site. This also qualifies as awareness information.



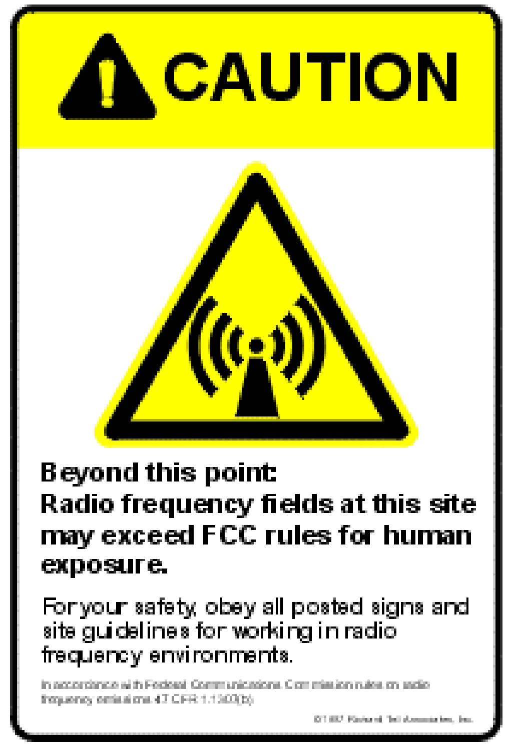
5.2 Notice

The notice sign is used to distinguish the boundary between the General Population/Uncontrolled and the Occupational/Controlled areas. This boundary will usually be the fence for the property, gate entrance, or roof door to the equipment room. The limits associated with this notification must be less than the Occupational/Controlled MPE. All sites have standard guidelines posted that must be obeyed and understood by all workers. These guidelines will ensure the area is maintained below Occupational/Controlled MPE. EME awareness training is recommended for all workers.



5.3 Caution

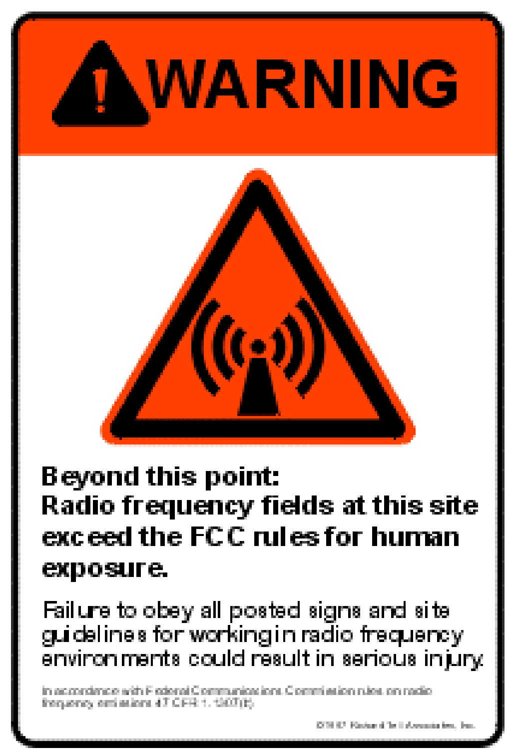
The caution sign identifies RF controlled areas where RF exposure can exceed the Occupational/Controlled MPE. Generic guidelines apply in all situations and will be posted at all sites; however, site specific guidelines may be associated with some areas to ensure work is always performed in compliance with the FCC guidelines. Such site specific guidelines may require reduction of RF power before work begins or the use of RF protective clothing. In no case should workers enter and work in these areas without understanding and obeying the necessary procedures. All authorized workers for RF controlled areas must have EME awareness training.



5.4 Warning

The warning sign denotes the boundary of areas with RF levels substantially above the FCC limits, normally defined as those greater than ten (10) times the Occupational/Controlled MPE.

Telecommunication contractors and employees should not enter these areas unless special procedures are followed. These situations typically are associated with broadcast transmitters operating at high powers. If work is required in these areas the broadcast transmitter must be shut down for the duration of the maintenance. Engineering evaluation must be performed to determine the proper special procedures required before this area can be entered.



6. PERSONAL PROTECTIVE EQUIPMENT (PPE)

6.1 Protective Clothing

There may be situations where field analysis shows areas that are not in compliance with the Occupational/Controlled MPE. After all options are considered and if the situation cannot be controlled with engineering or work practice solutions, implementation of Personal Protective Equipment (PPE) may be the only solution. An example of this type of situation may be a rooftop that has collocated broadcast in the vicinity of a heavily congested antenna field. In certain situations where building architectural concerns are a priority there may be no simple solution available to reduce the fields. The only solution may be the use of RF protective clothing as a means to reduce EME exposure.

RF protective clothing was introduced into the United States several years ago by a German manufacturer (NSP)[3] and sold under the name Naptex™. The suit consists of work coveralls with an integral hood for head protection. The suit is constructed of a polyester yarn, which is wound coaxially around stainless steel fibers. This provides uniform consistency of material and attenuating metal. Tests[4,5] have shown that the suit can effectively provide between 10 dB and 12 dB of reduction in EME absorption within the body at virtually any frequency over the telecommunications spectrum. This would indicate that use of the suit could compensate for exposure to EME fields as great as 1000% above the FCC Occupational/Controlled MPE values. Additional testing has shown the use of the suit without the hood in fields under 300% of the Occupational/Controlled MPE values at 900 MHz provides compliance with the peak SAR limits of 8 W/kg. The acceptable levels that the hoodless suit can be safely used increase as the frequency is reduced. Contractors should be notified if RF Protective Clothing or the hood is required for compliance.

6.2 Personal monitors

Work on specific antennas should only be accomplished after the appropriate transmitters have been turned off and locked out. This prevents anyone from accidentally activating the transmitters while others are performing maintenance. However, with the large number of transmitters combined into single antennas it becomes considerably more difficult to confirm that all transmitters are deactivated. The ideal method would be to have a RF light on the top of the antenna. The light would be off to confirm that there was no RF activity. A more practical approach would be to use a personal monitor. A personal monitor is an RF threshold detector that alarms when RF exceeds the threshold of the device, normally 50% Occupational/Controlled MPE. These devices are designed to detect a wide range of frequencies and can be used in most environments. When approaching an antenna that requires maintenance, the monitor should be placed near the antenna for a period of time, about 30 seconds should suffice. If the antenna is still active the monitor will alarm. This will show that there are still transmitters active, or if an alarm does not sounds, will confirm that all transmitters were deactivated. This provides a positive confirmation and allows the worker to insure they are working on inactive antennas.

Some manufactures of personal monitors propose they can be worn to indicate compliance. This use should be considered carefully because, when the device is used in accordance with its instructions, compliance is only confirmed at the location of the monitor. If, for example, the monitor is worn on the belt of a tower climber, the possibility of entering high fields without the monitor being activated exists. When climbing the head and shoulders can enter high fields without the monitor mounted on the belt alarming. This could provide a false indication of safety.

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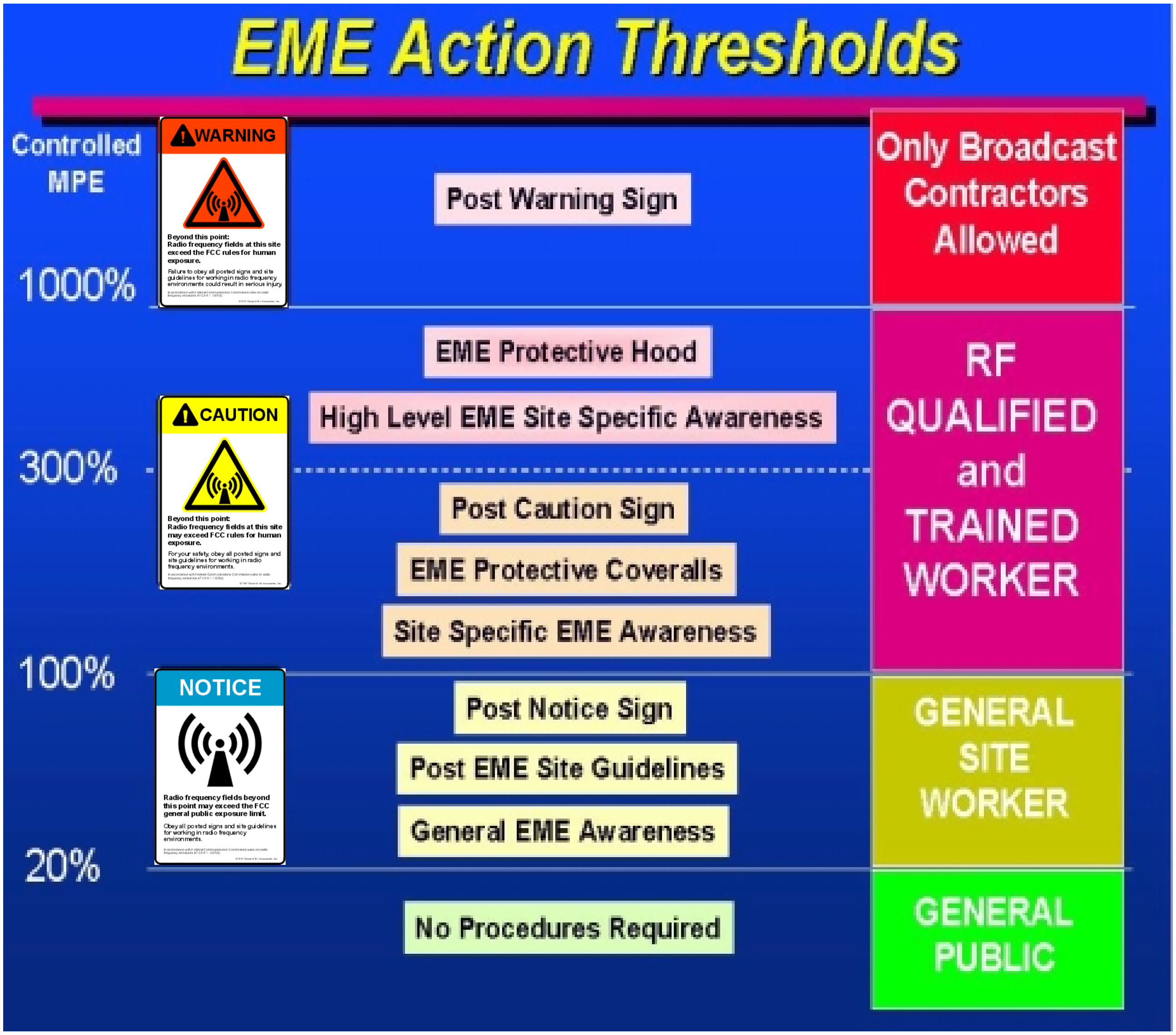
[3] See NSP World Wide Web site: www.nspworldwide.com

[4] Tell, R. A. (1995). *Engineering Services for Measurement and Analysis of Radiofrequency (RF) Fields.* Technical report for the Federal Communication Commission, Office of Engineering and Technology, Washington, DC, FCC/OET RTA 95-01 [NTIS order no. PB95-253829].

[5] Tell, R. A. (1996). *SAR Evaluation of the Naptex suit for use in VHF and UHF bands.* Presented at the International RF Safety Workshop, Schwangau, Germany, September 25-26.


EME Action Thresholds
Controlled MPE
1000%
300%
100%
20%
WARNING
Beyond this point: Radio frequency fields at this site exceed the FCC rules for human exposure.
Failure to obey all posted signs and site guidelines for working in radio frequency environments could result in serious injury.
CAUTION
Beyond this point: Radio frequency fields at this site may exceed FCC rules for human exposure.
NOTICE
Radio frequency fields beyond this point may exceed the FCC general public exposure limit.
Post Warning Sign
EME Protective Hood
High Level EME Site Specific Awareness
Post Caution Sign
EME Protective Coveralls
Site Specific EME Awareness
Post Notice Sign
Post EME Site Guidelines
General EME Awareness
No Procedures Required
Only Broadcast Contractors Allowed
RF QUALIFIED and TRAINED WORKER
GENERAL SITE WORKER
GENERAL PUBLIC